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Express Mail No. EV 313 841 988 US

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**
**BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES**

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| Application of: | Alexandre M. Zagoskin | Confirmation No.: | 1708 |
| Serial No.: | 09/452,749 | Art Unit: | 2814 |
| Filed: | December 1, 1999 | Examiner: | Douglas A. Wille |
| For: | PERMANENT READOUT SUPERCONDUCTING QUBIT | Attorney Docket No: | 11090-003-999 |

## BRIEF ON APPEAL FEE TRANSMITTAL

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

An original and two copies of the applicant's Brief on Appeal in the above-entitled application are submitted herewith. The item(s) checked below apply:

☐ The Brief filing fee is $330.00
☒ Applicant has qualified for the 50% reduction in fee for an independent inventor, nonprofit organization or small business concern and the Brief filing fee is $165.00

The brief filing fee is:

☒ Required.
☐ Not required. (Fee paid in prior appeal.)

Please charge the required Brief filing fee to Pennie & Edmonds LLP Deposit Account No. 16-1150. A copy of this sheet is enclosed.

Respectfully submitted,

Date: October 20, 2003

Gary S. Williams 31,066 (Reg. No.)
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Enclosure

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CA1: 357115.2

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## APPEAL BRIEF

Mail Stop Appeal Brief - Patents
Honorable Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

Sir:

This is an appeal pursuant to the provisions of 37 C.F.R. § 1.192 from the Examiner's final rejection of claims 1-18 and 28-65 of February 19, 2003. Claims 1, 3-5, 28, 29, 33, 34, 54, 56, 58, and 60-65 were rejected under 35 U.S.C. §103(a) as being unpatentable over Tinkham, *Introduction to Superconductivity*, Second Edition, McGraw-Hill, 1996 (hereinafter "Tinkham"), in view of United States Patent 5,157,466 to Char *et al.* (hereinafter "Char"). Further, claims 2, 30, 31 and 52 were rejected under 35 U.S.C. §103(a) as being unpatentable over Tinkham in view of Char and further in view of Shnirman *et al.*, Physical Review B 57, p. 15400, 1998 (hereinafter "Shnirman"). Further claims 6, 8-10, 35, 39-41, 53, 55, 57, and 59 were rejected under 35 U.S.C. §103(a) as being unpatentable over Tinkham in view of Char and further in view of United States Patent 3,953,749 to Baechtold *et al.* (hereinafter "Baechtold). Claims 7, 11-18, 36, 37, 42, 43, 45, 46, and 48-50 were rejected under 35 U.S.C. § 103(a) as being



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unpatentable over Tinkham in view of Char, Baechtold and further in view of Shnirman. Claims 32, 38, 44, 47, and 51 were also rejected under 35 U.S.C. § 103(a) as being unpatentable over Tinkham in view of Char, Baechtold and further in view of Shnirman.

The Notice of Appeal was filed and received by the United States Patent and Trademark Office on August 15, 2003. This Appeal Brief was originally due on October 15, 2003, for which an extension for a period of one (1) month is hereby requested in the Applicant's concurrently filed Petition for the Extension of Time under 37 C.F.R. § 1.136(a).

A "Brief on Appeal Fee Transmittal" and an amendment under 37 C.F.R. § 1.116 accompanies this brief.

## 1. REAL PARTY IN INTEREST

The real party in interest is D-Wave Systems, Inc. D-Wave Systems, Inc. is a Canadian corporation having headquarters at 320-1985 West Broadway, Vancouver, British Columbia, Canada, V6J 4Y3, by whom the Applicant is employed. An assignment of the invention was recorded on January 24, 2000.

## 2. RELATED APPEALS AND INTERFERENCES

There are no interferences or other appeals related to the present application.

## 3. STATUS OF CLAIMS

On August 15, 2003, Applicant appealed from the final rejection of claims 1-18 and 28-65. Upon entry of a 37 C.F.R § 116 amendment filed on even date herewith, claims 1-8, 11-18, 28, 30-39, and 42-65 remain in the application.

## 4. STATUS OF AMENDMENTS

Applicant has filed an amendment under 37 C.F.R § 116 on even date herewith. All other amendments filed by the Applicant have been duly entered by the Examiner.

## 5. SUMMARY OF THE INVENTION

The present invention is directed to structures used to perform quantum computing. As outlined on page 3, first paragraph, of DiVincenzo in *Scalable Quantum Computers*, Braunstein and Lo, *eds.*, Wiley-VCH, 2001, Berlin, (attached hereto as Exhibit A), a quantum computing device requires qubits. A qubit is a quantum two-level system (DiVincenzo, page 3, first paragraph). The feature that distinguishes a qubit from a bit is that the permitted states of a single qubit fill up a two-dimensional complex vector space $a|0\rangle + b|1\rangle$, where $a$ and $b$ are complex numbers and $|0\rangle$ and $|1\rangle$ are two distinct basis states. A qubit has a nonzero probability of occupying the states $|0\rangle$ and $|1\rangle$ at the same time. See page 2, lines 11-13, as well as page 2, line 20, through page 3, line 6, of the specification. By comparison, a conventional bit can only occupy the states "0" or "1".

For physical intuition of the dynamics of a qubit a particle with mass, termed a "phase particle", is visualized as moving along, under the effect of gravity, in a landscape that defines potential energy barriers. Since the phase particle is governed by quantum mechanics rather than classical mechanics, it is possible for the phase particle to tunnel through the energy barrier separating two ground states ($|0\rangle$ and $|1\rangle$). Tunneling permits the qubit to have a nonzero probability of occupying the two ground states $|0\rangle$ and $|1\rangle$ at the same time. This is in contrast to classical dynamics where a particle cannot tunnel under a barrier and where, to transition from one state to another, it must possess sufficient energy to be able to transition over the potential energy barrier.

The invention is directed to new types of quantum computing devices (*e.g.*, quantum computing structures, quantum registers, qubits) that exploit currents spontaneously arising in a superconductor in the vicinity of a grain boundary Josephson junction. See specification, page 6, lines 18-28. As described on page 3, lines 11-21, as well as Fig. 1A of the specification, these new types of quantum computing devices comprise a superconducting mesoscopic island 120 and a superconducting bank 110 formed on an insulating substrate 140. The mesoscopic island 120 and superconducting bank 110 are separated by a clean Josephson junction 130. At least one of the superconducting bank 110 and superconducting island 120 is a d-wave superconductor, which is a special form of superconductor.

Upon entry of the attached amendment under 37 C.F.R. § 1.116, the structures recited in each of the independent pending claims combines three features to form a quantum computing

device: (i) the use of a d-wave superconductor to form at least one of the superconducting bank 110 and island 120, (ii) a mesoscopic-sized island 120 and (iii) a clean Josephson junction 130 between the superconducting bank 110 and mesoscopic island 120. The purpose of each of these recited features in forming a quantum computing device will be discussed in turn.

5.1 Use of a d-wave superconductor to form at least one of a bank and a mesoscopic island

As explained on page 9, lines 6-17, of the specification, the use of a d-wave superconductor to form at least one of the superconducting bank 110 and mesoscopic island 120 causes persistent supercurrents to arise in the vicinity of clean Josephson junction 130. These persistent supercurrents are illustrated in Fig. 1A of the specification. This is a known phenomenon. For example, the second paragraph in column 1 of Lindström et al., 2003, Physical Review Letters 90, 117002, attached hereto as Exhibit D (hereinafter "Lindström"), notes that "[t]ime-reversal symmetry can ... be spontaneously violated and thus spontaneous currents generated."

5.2 Mesoscopic island

A mesoscopic island 120 is used in the claimed devices so that the phase of the persistent supercurrents discussed in Section 5.1 adopts quantum mechanical behavior rather than classical mechanical behavior. A mesoscopic system is any system that is small enough to be governed by quantum mechanical principles rather than classical mechanical principles. Here, a mesoscopic island 120 is a block of superconducting material that is sufficiently small to be governed by quantum mechanical principles. Generally, in order for island 120 to be mesoscopic, it must have dimensions that are in the low micrometer range or smaller. As noted on page 7, line 30, through page 8, line 2, of the specification, an exemplary mesoscopic island has a width that is 0.2 microns or less, a length of 0.5 micron or less, and a thickness that is 0.2 microns or less. The determination of whether an island 120 is mesoscopic is realized by coherent tunneling of the phase of the persistent supercurrents. Tunneling is a uniquely quantum phenomenon. If island 120 is mesoscopic, then the phase of the persistent supercurrents has a nonzero probability of being in one of two degenerate states. If island 120 is too large to be mesoscopic, then the phase of the persistent supercurrents adopts a constant value, does not have two degenerate ground states, and cannot support quantum computing.

5.3 Clean Josephson junction between a bank and a mesoscopic island

One of the requirements of quantum computing is the establishment of two basis states (*e.g.*, two degenerate states). See specification page 2, lines 11-13. In the novel structures of the present invention, Applicant takes advantage of the properties of a clean Josephson junction in which at least one side of the junction is d-wave superconductor. As noted on page 7, lines 12-14, of the specification, and as illustrated in Fig. 1A, a clean junction 130 separates a bank 110 and island 120. Then, on page 9, lines 6-28, of the specification it is stated that junction 130 causes a non-zero supercurrent in the ground state that is represented by two different states each of which has the same potential energy. In other words, the two different states are degenerate. Page 9 of the specification further states that the two degenerate states correspond to minimal supercurrents circulating through Josephson junction 130 in clockwise and counterclockwise senses. Page 9, lines 15-17, indicate that the two degenerate states associated with the supercurrent on island 120 (*i.e.*, the clockwise and counterclockwise currents respectively) permit quantum computing. The clockwise and counterclockwise supercurrents described on page 9 of the specification serve as the basis states needed for quantum computing. As noted on page 9, lines 27-28, quantum tunneling between these basis states (the two degenerate states) causes the state of island 120 to evolve. This means that the phase of the persistent supercurrents can tunnel through the energy barrier that separates the degenerate state represented by the clockwise persistent supercurrent and the degenerate state represented by the counterclockwise persistent supercurrent through a phenomenon that is known as quantum mechanical tunneling. Furthermore, because the two states are degenerate, this quantum tunneling can occur in both directions (*i.e.*, from $|0\rangle$ to $|1\rangle$ and vice versa) without the application of an external force on the qubit. Due to the quantum mechanical tunneling between the two degenerate states, there is a nonzero probability that states $|0\rangle$ and $|1\rangle$ (where $|0\rangle$ is arbitrarily assigned to either the clockwise or counterclockwise supercurrent and $|1\rangle$ is assigned to the other supercurrent) are occupied at the same time, hence satisfying a central requirement for forming a qubit capable of quantum computation. As noted on page 9 of the specification, the coexistence of the two degenerate ground states results in the coexistence in persistent supercurrents that are traveling in opposite directions (clockwise and counterclockwise as viewed using the framework of Fig. 1A). Because the claimed devices are superconducting, these clockwise and counterclockwise

currents do not interact with each other. Thus, no energy is lost and the persistent supercurrents can coexist for long periods of time. This phenomenon is also described in Lindström et al., 2003, page 117002-1, (Exhibit D) bridging paragraph between columns 1 and 2.

Table 1 summarizes the three novel features of the present invention, how they contribute to the formation of a quantum computing device, and where they are described in the specification.

Table 1. Features that are recited in each pending independent claim.

| FEATURE | CONTRIBUTION | SUPPORT IN SPECIFICATION |
|---|---|---|
| Use of a d-wave superconductor to form at least one of the bank 110 and mesoscopic island 120 across a Josephson junction. | Causes persistent supercurrents to arise in the vicinity of the Josephson junction. | Page 7, lines 6-11 |
| Mesoscopic island 120. | Causes the persistent supercurrents to adopt quantum mechanical behavior, including the ability for the phase of the persistent supercurrents to spontaneously tunnel through a potential energy barrier between degenerate phase states (basis states). | Page 7, line 27, through page 8, line 2 |
| Clean Josephson junction between bank 110 and mesoscopic island 120. | Causes the persistent supercurrents to have two degenerate phase states (basis states). | Page 7, lines 12-16; page 9, line 29, through page 10, line 7 |

## 6. ISSUES

Upon entry of the amendment under 37 C.F.R. § 1.116 filed on even date herewith, the issues presented are:

(1) whether claims 1, 3-5, 28, 33, 34, 54, 56, 58, and 60-65 are patentable under 35 U.S.C. § 103(a) over Tinkham in view of Char;

(2) whether claims 2, 30, 31 and 52 are patentable under 35 U.S.C. § 103(a) over Tinkham in view of Char and further in view of Shnirman;

(3) whether claims 6, 8, 35, 39, 53, 55, 57, and 59 are patentable under 35 U.S.C. § 103(a) over Tinkham in view of Char and further in view of Baechtold;

(4) whether claims 7, 11-18, 36, 37, 42, 43, 45, 46, and 48-50 are patentable under 35 U.S.C. § 103(a) over Tinkham in view of Char, Baechtold and further in view of Shnirman;

(5) whether claims 32, 38, 44, 47, 51 are patentable under 35 U.S.C. § 103(a) over art not specifically identified by the Examiner; and

(6) whether claims 1-8, 11-18, 28, 30-39, and 42-65 are patentable under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claims 1-6, 12, 14, 15, and 18-25 of U.S. Patent No. 6,459,097 in view of Char.

## 7. GROUPING OF CLAIMS

Claims 1-8, 11-18, 28, 30-39, and 42-65 are pending in this case. Many of the pending claims are believed to be separately patentable for the reasons set forth in Section 8 below and do not stand or fall together. In particular, at least the two following groups are believed to be separately patentable:

Group I: claims 1-8, 11-18, 28, 30-39, 42-59, and 64-65; and

Group II: claims 60-63

## 8. ARGUMENTS

### 8.1 Group I: Claims 1, 8, 28, 39, 60, and 64 and each of the claims that depend from these independent claims

In the final office action mailed February 19, 2003, the Examiner rejected claim 1 under 35 U.S.C. § 103(a) as being unpatentable over Tinkham in view of Char. Claim 1 recites (i) a first bank of a superconducting material, (ii) a mesoscopic island of a superconducting material, where at least one of the island and the bank comprises a d-wave superconducting material, and (iii) a clean Josephson junction between the island and the bank. In fact, upon entry of the 37 C.F.R. § 1.116 amendment filed concurrently with this Appeal Brief, each of the independent

claims (claims 1, 8, 28, 39, 60, and 64) recite at least these three elements in a quantum computing device (*e.g.* a quantum computing structure, a quantum register, or a qubit).

The Examiner asserts that page 248, top paragraph, of Tinkham shows a small superconducting island connected to charge reservoirs and further, page 256, last full paragraph, shows a small superconducting island connected to two macroscopic superconducting leads. Next, the Examiner points out that column 2, line 3 et seq. and Fig. 14 of Char show the formation of a grain boundary Josephson junction 314 of high temperature superconductor material where an island 310 is connected to a body 312. The Examiner states that it would have been obvious to use the Char structure for the Tinkham device "since it is known to be functional." Although neither Char nor Tinkham teach or suggest a clean Josephson junction, the Examiner states that it would be obvious to provide the best quality crystal structures since this is standard in semiconductor processing. When rejecting claims under 35 U.S.C. § 103, the PTO bears the burden of establishing a *prima facie* case of obviousness. *In re Bell*, 26 USPQ2d 1529 (Fed. Cir. 1993). To establish a *prima facie* case, the prior art reference, or references when combined, must teach or suggest each and every limitation of the claimed invention. MPEP § 706.02(j). The teaching or suggestion to make the claimed invention and the reasonable expectation of success must both be found in the prior art, not in the Applicant's disclosure. *In re* Vaeck, 20 USPQ2d 1438 (Fed. Cir. 1991). There must be some motivation, suggestion, or teaching of the desirability of making the specific combination that was made by the Applicant. *In re Fine*, 837 F.2d 1071, 1075 (Fed. Cir. 1988).

In the present instance, one relevant inquiry is whether the cited art, either alone or in combination, teaches each and every limitation of the rejected claims. To this end, Applicant submits that the Examiner's rejection of the claims is unfounded because Char and Tinkham, either alone or in combination, do not teach or suggest the clean Josephson junction(s) that are recited in each of the independent claims. Another relevant inquiry is whether the prior art provides one of ordinary skill in the art with a suggestion or motivation to modify or combine the teachings of the references relied upon by the Examiner to arrive at the claimed invention. As discussed in detail below, the cited art fails to satisfy either of these requirements.

8.1.1 Char does not teach or suggest a clean Josephson junction

Each of the independent claims recites at least one clean Josephson junction. In the February 19, 2003 Office Action, the Examiner stated that the clean Josephson junction limitation in claim 1 does not render the claim patentable over the combination of Char and Tinkham. The Examiner reasoned that it would have been obvious to provide the best quality crystal structures since this is standard in semiconductor processing. The Applicant will discuss the current-phase relationship of Josephson junctions made from conventional superconducting materials and unconventional superconducting materials in Section 8.1.1.1. Then, the current-phase relationship of clean Josephson junctions will be discussed in Section 8.1.1.2. Then, in subsequent sections, the Applicant will discuss why Char and Tinkham do not teach or suggest clean Josephson junctions and why there is no motivation to modify Char to incorporate clean Josephson junctions into Char devices.

8.1.1.1 Josephson junction current-phase relationships

In general, the current-phase relation of a Josephson junction is described by an odd periodic function commonly represented by the Fourier expansion:

$$I(\varphi) = I_1 \cdot \sin(\varphi) + I_2 \cdot \sin(2\varphi) + \ldots, \qquad (1)$$

where $I_1$ and $I_2$ represent the critical current of the first and second harmonics respectively. In Josephson junctions formed out of conventional superconducting materials, the second harmonic term and higher terms are negligible. See Il'ichev *et al.*, 1999, Physical Review B 60, p. 3096, (hereinafter "Il'ichev 1999"), second column ("The $I_2$ term is also present in weak links based on conventional *s*-wave superconductors but for all known types of weak links $|I_2 / I_1| < 1$. For instance, for a tunnel junction $|I_2 / I_1| << 1$").

The order parameter of a superconducting material determines the properties and characteristics of the superconducting material, and hence the current-phase relationship of weak links formed in the material. Conventional superconducting materials have isotropic order parameters. In contrast, unconventional superconducting materials have anisotropic order parameters. A common unconventional superconducting material is the d-wave superconductor

$YBa_2Cu_3O_{7-x}$ (YBCO), which is used in both Char and Il'ichev 1999. The term "d-wave" indicates the type of symmetry of the anisotropic order parameter.

Due to the anisotropy of the d-wave order parameter, the current-phase relationship for a Josephson junction in a d-wave superconductor has the potential of having a temperature dependent second harmonic term. The current-phase relationship of the Josephson junctions described in Il'ichev 1999 is:

$$I_P = I_c^I \cdot \sin(\varphi) + I_c^{II} \cdot \sin(2\varphi), \qquad (2)$$

where $I_c^I$ and $I_c^{II}$ are the critical currents of the first and second harmonics respectively. Il'ichev 1999 established that the realized non-sinusoidal behavior in the current-phase relationship of this clean Josephson junction is explained by the presence, and in some cases dominance, of the second harmonic term. See, for example, Fig. 4 of Il'ichev 1999, where the second order harmonic $I_2$ dominates over the first order harmonic $I_1$ at lower temperatures.

<u>8.1.1.2 Clean Josephson junctions</u>

The greater the influence of the second harmonic in the current-phase relationship of a Josephson junction, the greater the deviation from conventional $2\pi$ periodic sinusoidal behavior. A clean Josephson junction is defined by a current-phase relationship in which the second harmonic makes a distinct contribution to the characteristics of the junction. (See point 5 of the declaration of Dr. Alexander Tzalenchuk under 37 C.F.R. § 1.132 submitted in response to the February 19, 2003 Office Action on April 18, 2003, attached hereto as Exhibit H). In terms of Eqn. 2, this is the regime where $I_c^{II} > I_c^I / 2$, which causes the equilibrium state to shift from $\varphi=0$, in the sinusoidal case, to about $\pm\pi/2$, creating a double degenerate ground state phase difference across the junction. In other words, the phase differences of about $+\pi/2$ and $-\pi/2$ have equal energy across the unconventional superconductor clean Josephson junction.

The double degenerate ground state associated with a clean Josephson junction is used in the present invention in order to cause persistent supercurrents that spontaneously arise in the claimed devices to have two degenerate ground states. See page 9, lines 6-28, of Applicant's

specification. As discussed in Section 5.1, such persistent supercurrents arise spontaneously in the vicinity of the clean Josephson junction when at least one of bank 110 and island 120 (Applicant's Fig. 1A) is made of a d-wave superconducting material. As discussed in Il'ichev 1999, page 3098, first column, and as depicted in Fig. 4 of Il'ichev 1999 (Exhibit B), the size of the second harmonic is dependent on temperature. It can be suppressed by raising the temperature of the junction. When the second harmonic is suppressed, the junction behaves as a conventional Josephson junction.

8.1.1.3 Char

Char does not teach or suggest clean Josephson junctions. The current-phase relationship of a Josephson junction comprised of a conventional superconducting material has a sinusoidal dependence. See Il'ichev, 1998, Physical Review Letters 81, p. 894, first column, "[t]his sinusoidal dependence has been confirmed experimentally numerous times for standard tunnel junctions between conventional superconductors"). Il'ichev 1998 is attached hereto as Exhibit C. Il'ichev 1998 describes the fabrication of clean Josephson junctions in unconventional superconductors and measurement of their current-phase relationship. Il'ichev 1998 predicted and found significant deviations from the sinusoidal dependence that is typical of conventional Josephson junctions (See Il'ichev 1998, p. 896, first column, "strong deviations from the standard sinusoidal dependence have been predicted for the current-phase relations of various configurations of Josephson junctions employing such unconventional superconductors"). Il'ichev 1999 (Exhibit B) found that the deviations from the sinusoidal dependence were temperature dependent (Il'ichev, page 3098, column 1, "the amplitude of the $\pi$-periodic component of the CPR decreases drastically with increasing temperature").

A review of Fig. 15 of Char is instructive. As illustrated in Fig. 15 of Char, the voltage phase properties of the Char devices illustrate temperature independent conventional sinusoidal behavior, indicating that the second harmonic is suppressed at *all* temperatures in complete contrast to the teachings of Il'ichev 1999 (Exhibit B, p. 3098 column 1, first full paragraph). In other words, Fig. 15 of Char shows that the Char devices "operate properly" (*i.e.*, exhibits $2\pi$ periodic sinusoidal behavior) at temperatures ranging from 4.2K to 77K (see Char, column 15, lines 35-40). This indicates that the Josephson junctions of Char are not in the clean regime. If the Char devices were in the clean regime, then the voltage phase relationship of a Char device

would adopt a sinusoidal waveform at high temperatures (68K) and a non-sinusoidal waveform at low temperatures (4.2K). Fig. 3 of Il'ichev 1999 (p. 3098) shows such a temperature dependence. In Fig. 3 of Il'ichev 1999 (Exhibit B), the non-sinusoidal behavior of a Josephson junction capable of exhibiting second harmonic effects is lost as the temperature of the junction is shifted from 4.2K to 40K. Thus, Char describes Josephson junctions for which the second harmonic is suppressed between 4.2K and 77K. This means that Char does not teach or suggest clean Josephson junctions.

<u>8.1.2 Tinkham does not teach or suggest a clean Josephson junction</u>

Tinkham does not remedy the deficiencies of Char. In particular, Tinkham does not teach or suggest a clean Josephson junction. As noted by the Examiner on page 2 of the February 19, 2003 office action, Tinkham does not detail the materials of the island, leads to the island or Josephson junctions.

<u>8.1.3 There is no motivation in the art to modify Char so that it would have a clean Josephson junction</u>

In the February 19, 2003 Office Action, the Examiner stated that it would have been obvious to provide the best quality crystal structures since this is the standard in semiconductor processing. Applicant respectfully submits that the practice of providing the best quality crystal structures would not have resulted in the modification of Char or Tinkham to include clean Josephson junctions at the time the present application was filed for two reasons. First, the Char devices were constructed using biepitaxial technology. Even the best biepitaxial technology available at the time the present application was filed could not have achieved the unconventional superconductor clean Josephson junctions recited in the pending claims. Second, even if it were possible to modify Char to make the claimed junctions, such junctions would have electrical characteristics that are undesirable for the conventional devices proposed by Char. Because of these undesirable electrical characteristics, their use in the conventional electronic devices described in Char would result in unsatisfactory device performance. This reasoning is outlined in the following subsections.

8.1.3.1 <u>Neither Char nor the best quality crystal structures available for biepitaxial Josephson junction technology at the time of filing of the application were sufficiently advanced to make a clean Josephson junction.</u>

In order to produce a Josephson junction in a d-wave superconducting material such as $YBa_2Cu_3O_{7-x}$ (YBCO), the two sides of the junction must have different crystallographic orientation. There are three general approaches to fabricating such junctions, bicrystal, biepitaxial, and step-edge. See page 1, middle of column 2, of Tafuri *et al.*, cond-mat/0010128.1, Oct. 9, 2000, attached hereto as Exhibit E "YBCO GB junctions are usually classified as bicrystals, biepitaxials, and step-edges, depending on the fabrication procedure." While not intending to be limited to any particular fabrication technique, Applicant discloses a bicrystal fabrication technique on page 8, lines 3-18, of the specification. In Applicant's bicrystal fabrication technique, the substrate itself is a bicrystal substrate, such as a strontium-titanate bicrystal. When a d-wave superconductor such as YBCO is grown or deposited on the bicrystal substrate, it produces two banks having different orientations. On page 8 of the specification, Applicant cites and incorporates by reference Il'ichev *et al.*, 1998 cond-mat/9811017, which is attached hereto as Exhibit F. Page 2, bridging paragraph between columns 1 and 2 of Il'ichev 1998, disclose more details of the bicrystal fabrication technique. Further, the reference demonstrates the successful use of the fabrication technique to make clean Josephson junctions in YBCO. As noted by Tafuri *et al.*, bicrystal techniques typically offer junctions with better performances than biepitaxials (Tafuri, Exhibit E, page 1, second column, "[t]he bicrystal technique typically offers junctions with better performances").

Char uses a biepitaxial technique to form Josephson junctions. In the Char biepitaxial approach, a seed layer is introduced onto a portion of the substrate. See, for example, element 42 in Figs. 3-10 of Char. When YBCO is grown or deposited on a substrate that includes the seed layer, the YBCO overlying the seed layer adopts a different orientation than the portion of the substrate that does not overlay the seed layer. The boundary, therefore, between the YBCO overlying the seed layer and the YBCO overlying the native substrate forms a Josephson junction. See, for example, Fig. 3 of Char, including the Josephson junction (element 30).

Biepitaxial grain boundary Josephson junction technology was not sufficiently advanced at the time of filing of the instant Application to form clean Josephson junctions. This is evidenced by Tafuri (Exhibit E). Tafuri provides new experimental procedures to produce

biepitaxial YBCO Josephson junctions. On page 1 of Tafuri, it is noted that these experimental techniques could *possibly* be used to obtain a Josephson junction that has a double degenerate state [*i.e.*, a clean Josephson junction, "[i]n this paper we discuss how $YBa_2Cu_3O_{7-x}$ (YBCO) structures made by the biepitaxial technique can be successfully employed to produce arbitrary circuit geometries in which both "0" and $\pi$-loops are present, and possibly to obtain a doubly degenerate state"]. Further, it is noted that the biepitaxial techniques of Tafuri represent significant improvements over the biepitaxial techniques of Char (Tafuri, page 1, second column, referencing Char *et al.*, 1991, Applied Physics Letters 59, p. 733, attached hereto as Exhibit G, "we intend to show that significant improvements with respect to the original technique developed by Char et al. are possible for biepitaxial junctions, and that the resulting devices have potential for applications"). The Char *et al.* reference cited by Tafuri is the same biepitaxial technology that is disclosed in United States Patent 5,157,466 to Char. Compare, for example, the text beginning on the second full paragraph on p. 733, column 2 of Char, Applied Physics Letters 59, to column 9, lines 49-64 of United States Patent 5,157, 466. Also, compare Figs. 2, 3, and 4 of Char, Applied Physics Letters 59 to Figs. 13, 14, and 15 of United States Patent 5,157, 466. Clearly, when Tafuri was published, more than ten months after the time of filing Applicant's application, biepitaxial techniques that *might* produce double degenerate (clean) Josephson junctions in YBCO were only first being proposed. Given the difficulties with biepitaxial technology at the time the present application was filed, one of ordinary skill in the art would not have been able to modify Char to produce the devices claimed in the instant application. As such, the combination of Char and Tinkham does not provide a motivation to modify such references in order to make the claimed devices.

#### 8.1.3.2 Unpredictability of the second harmonic in clean Josephson junctions

Even if biepitaxial technology could be used to make a clean Josephson junction, the prior art does not provide a fair motivation to make such junctions. As discussed above, the current-phase relationship of a clean Josephson junction is nonsinusoidal, due to contributions from the second harmonic term, whereas a conventional Josephson junction is sinusoidal, due to the dominance of a first harmonic term and the suppression of a second harmonic term. Further, at least in the case of a YBCO thin film with asymmetric 45 degree [001]-tilt grain boundaries,

the contribution from the second harmonic term in clean Josephson junctions is temperature dependent. Thus, the use of clean Josephson junctions in the devices of Char would introduce an unpredictable temperature dependence on the current-phase dependence in such devices. Since the devices of Char are typically used in applications such as the precise measurement of magnetic fields (Char, column 2, lines 15-17, "[w]eak-link junctions make it possible to create extremely sensitive instruments to measure magnetic field, voltage, and current"), this unpredictable current-phase dependence is undesirable.

The unpredictability in the current-phase relationship of clean Josephson junctions, comes from at least two sources. First, as discussed above and as illustrated in Il'ichev 1999 (Exhibit B, e.g., Figs. 3 and 4), the second harmonic contribution associated with a clean Josephson junction is temperature dependent. Second, as detailed in Il'ichev 1999 and in Lindström, state of the art methods for manufacturing clean Josephson junctions still have not developed to the point where the strength of the second harmonic can be precisely engineered. In Il'ichev 1999, six bicrystal YBCO Josephson junctions were fabricated and studied. Of the six samples, only four produced clean Josephson junctions (Il'ichev 1999, page 3097, column 2, "[w]e have studied six samples, out of which for four samples the $\pi$-periodic component $I(\phi)$ was experimentally observed"). Furthermore the second harmonic contribution of each of the six samples was different (See Il'ichev 1999, column 2, page 3097). Lindström fabricated a number of devices that include Josephson junctions in YBCO using bicrystal techniques. Lindström reported that the critical current varied from sample to sample (Lindström, Exhibit D, page 117002-2, column 2, third full paragraph). Further, Lindström found that the first order and second order harmonics varied by as much as ten times between the two junctions in each of the manufactured devices. (Lindström, page 117002-4, column 1, first paragraph "[t]he ratios of $I_c^I$ and $I_c^{II}$ can vary as much as 10 times between two junctions in the same SQUID"). Thus, even the state of the art methods for manufacturing clean Josephson junctions such as Il'ichev 1999 and Lindström have failed to make clean Josephson junctions with consistent second order harmonics.

The results of Il'ichev 1999 and Lindström show that each clean Josephson junction would have to be characterized to determine the magnitude of the first and second harmonics. Such a step is not presently needed in Char and there is simply no motivation to alter Char to introduce such a step since Char does not teach or suggest the use of devices that make use of the

second order harmonics of clean Josephson junctions. In contrast, characterization of each clean Josephson junction for use in the quantum devices claimed by Applicant provides no drawback.

8.1.4 The prior art provides no motivation to combine Tinkham and Char

If it is not shown that the prior art gives a reason or motivation to make the claimed invention, then there is no *prima facie* case and the Applicant should prevail. *In re Grabiak*, 769 F.2d 729 (Fed Cir 1985). It is improper to use hindsight reconstruction based upon the disclosure of the Applicant's own specification. These type of hindsight rejections are specifically prohibited. See *In re Vaeck*, 947 F.2d 488, 493, 20 U.S.P.Q.2d 1438, 1442 (Fed. Cir. 1991); and *In re Fine*, 837 F.2d 1071, 1075, 5 U.S.P.Q.2d 1596 (Fed. Cir. 1988).

Even if Char were combined with Tinkham, the present invention would not be obvious since neither of them teaches the specific claimed structures as explained above. In addition, there is nothing in the references to motivate one of ordinary skill in the art to modify the structures disclosed in the cited references to arrive at the claimed invention. The Applicant's own disclosure cannot be used to fill the gap between the cited references and the claimed invention.

8.1.5 Conclusion

For the above-identified reasons, claims 1, 8, 28, 39, 60, and 64 are patentable over any combination of Tinkham and Char. Furthermore, all other pending claims depend from one of these claims and are therefore patentable over the combination of Tinkham and Char for at least the same reasons. Certain claims are rejected as being unpatentable over Tinkham, in view of Char and further in view of Baechtold. However, Baechtold merely teaches a binary circuit consisting of a series/parallel arrangement of Josephson junctions. As such, Baechtold does not remedy the above-identified deficiencies in the combination of Tinkham and Char. Certain of the claims are rejected as being unpatentable over Tinkham, in view of Char, in view of Shnirman. However, Shnirman merely teaches a single-electron transistor capacitively coupled to a Josephson junction qubit. As such, Shnirman does not remedy the above-identified deficiencies in the combination of Tinkham and Char. Certain of the claims are rejected as being unpatentable over Tinkham, in view of Char, Baechtold, and further in view of Shnirman. None of these references, either alone or in combination, remedy the above-identified deficiencies. For

these reasons, all the claims are patentable over any combination of Tinkham, Char, Baechtold, and Shnirman. Additional reasons for patentability of some of the pending claims are provided in the following subsection.

8.2 Group II: Claims 60-63

Claims 60-63 are directed to a qubit with circuitry to allow selective interruption of quantum tunneling between a first ground state and a second ground state. In the February 19, 2003, Office Action, the Examiner stated that claims 60-63 are unpatentable over Tinkham in view of Char because Char shows a superconducting quantum interference device (SQUID) and the Examiner argued that tunneling occurs in such devices. While tunneling may in fact occur in such devices, it is not quantum tunneling as claimed in claims 60-63. Quantum tunneling can only arise in a mesoscopic system. Char does not teach or suggest a SQUID that is mesoscopic. Tinkham teaches a mesoscopic island but does not teach or suggest a SQUID. Furthermore, there is no suggestion in either reference nor any motivation in the art to combine the two references to make a mesoscopic SQUID.

8.3 The rejection of the pending claims under the judicially created doctrine of obviousness-type double patenting has been overcome.

Claims 1-18 and 28-65 were provisionally rejected under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claims 1-6, 12, 14, 15, and 18-25 of U.S. Patent No. 6,459,097 in view of Char. With respect to claims 9, 10, 29, 40, and 41, the rejection is moot because these claims have been canceled. A Terminal Disclaimer in compliance with 37 CFR 1.321 was submitted on April 18, 2003 along with the April 18, 2003 response to the February 19, 2003 Final Office Action. Accordingly, reversal of the double patenting rejection is respectfully requested.

## 9. CONCLUSION

For all of the foregoing reasons, reversal of the rejections of claims 1-8, 11-18, 28, 30-39, and 42-65 is respectfully requested.

Respectfully submitted,
PENNIE & EDMONDS LLP

Date: Oct. 20, 2003

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## APPENDIX A

## APPEALED CLAIMS (UPON ENTRY OF THE ACCOMPANYING AMENDMENT UNDER 37 C.F.R. § 1.116)

1. (previously amended) A quantum computing structure comprising:

a first bank of a superconducting material having a first crystal orientation;

a mesoscopic island of a superconducting material having a second crystal orientation, wherein at least one of the island and the bank comprises a d-wave superconducting material; and

a clean Josephson junction between the island and the bank.

2. (original) The structure of claim 1, further comprising a single electron transistor connected between the island and ground.

3. (previously amended) The structure of claim 1, wherein the clean Josephson junction comprises a grain boundary between the bank and the island.

4. (original) The structure of claim 1, wherein the island comprises a d-wave superconducting material.

5. (original) The structure of claim 4, wherein the bank comprises a d-wave superconducting material.

6. (original) The structure of claim 1, further comprising:

a second bank of superconducting material having a third crystal orientation; and

a Josephson junction between the first and second banks.

7. (original) The structure of claim 6, further comprising a single electron transistor coupled between the second bank and the island.

8. (currently amended) A quantum register comprising:

a bank of a superconducting material;

a plurality of mesoscopic islands of superconducting material; and

a plurality of clean Josephson junctions, each clean Josephson junction being between the bank and a corresponding one of the islands, wherein at least one of the plurality of mesoscopic islands and the bank comprises a d-wave superconducting material.

9-10. (cancelled)

11. (original) The quantum register of claim 8, further comprising a plurality of single electron transistors, each electron transistor being between ground and a corresponding one of the islands.

12. (original) The quantum register of claim 8, further comprising a first plurality of single electron transistors, each single electron transistor in the first plurality being between islands in a corresponding pair of the islands.

13. (previously amended) The quantum register of claim 12, further comprising a second plurality of single electron transistors, each single electron transistor in the second plurality being between ground and a corresponding one of the plurality of mesoscopic islands.

14. (original) The quantum register of claim 8, further comprising:

a second bank of superconducting material; and

a Josephson junction between the first and second banks.

15. (original) The quantum register of claim 14, further comprising a first plurality of single electron transistors, each single electron transistor being coupled between the second bank and a corresponding one of the islands.

16. (original) The quantum register of claim 15, further comprising a second plurality of single electron transistors, each single electron transistor in the second plurality being between ground and a corresponding one of the islands.

17. (original) The quantum register of claim 15, further comprising a second plurality of a single electron transistors, each single electron transistor in the second plurality being between islands in a corresponding pair of the islands.

18. (previously amended) The quantum register of claim 17, further comprising a third plurality of single electron transistors, each single electron transistor in the third plurality being between ground and a corresponding one of the plurality of mesoscopic islands.

28. (currently amended) A qubit, comprising:

a first bank of a superconducting material having a first crystal orientation;

a mesoscopic island having a second crystal orientation formed adjacent to the first bank; and

a clean Josephson junction formed between the first bank and the mesoscopic island, wherein the first crystal orientation and the second crystal orientation are different wherein at least one of the mesoscopic island and the first bank comprises a d-wave superconducting material.

29. (cancelled)

30. (previously added) The qubit of Claim 28, further including a grounding mechanism coupled between the mesoscopic island and a ground.

31. (previously added) The qubit of Claim 30, wherein the grounding mechanism is a single electron transistor.

32. (previously added) The qubit of Claim 30, wherein the grounding mechanism is a parity key.

33. (previously added) The qubit of Claim 28, wherein the clean Josephson junction includes a grain boundary between the island and the first bank.

34. (previously added) The qubit of Claim 28, wherein the clean Josephson junction includes a normal metal.

35. (previously added) The qubit of Claim 28, further comprising:
a second bank of superconducting material having a third crystal orientation; and
a Josephson junction formed between the first bank and the second bank.

36. (previously added) The qubit of Claim 35, further comprising:
a coupling mechanism coupled between the mesoscopic island and the second bank.

37. (previously added) The qubit of Claim 36, wherein the coupling mechanism includes a single electron transistor.

38. (previously added) The qubit of Claim 36, wherein the coupling mechanism includes a parity key.

39. (currently amended) A quantum register, comprising:
a first bank of superconducting material;
at least one mesoscopic island of a superconducting material; and
at least one clean Josephson junction, each clean Josephson junction in said at least one clean Josephson junction formed between a mesoscopic island in the at least one mesoscopic island and the first bank, wherein at least one of the at least one mesoscopic island and the first bank comprises a d-wave superconducting material.

40-41. (cancelled)



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42. (previously added) The quantum register of Claim 39, further including at least one first coupling mechanism, each of the at least one first coupling mechanisms coupling a corresponding one of the at least one mesoscopic islands to ground.

43. (currently amended) The quantum register of Claim 42, wherein ~~at~~ said at least one ~~of the~~ first coupling mechanism ~~mechanisms~~ includes a single electron transistor.

44. (currently amended) The quantum register of Claim 42, wherein ~~at~~ said at least one ~~of the~~ first coupling mechanism ~~mechanisms~~ includes a parity key.

45. (currently amended) The quantum register of Claim 39, wherein said at least one mesoscopic island includes a ~~at least one~~ pair of mesoscopic islands that are coupled to each other by a second coupling mechanism.

46. (previously added) The quantum register of Claim 45, wherein the second coupling mechanism includes a single electron transistor.

47. (previously added) The quantum register of Claim 45, wherein the second coupling mechanism includes a parity key.

48. (previously added) The quantum register of Claim 39, further including:

a second bank of superconducting material; and

a Josephson junction formed between the second bank and the first bank.

49. (currently amended) The quantum register of Claim 48, further including ~~at least one~~ a third coupling mechanism coupled between ~~one of the~~ a mesoscopic ~~islands~~ island in said at least one mesoscopic island and the second bank.

50. (previously added) The quantum register of Claim 49, wherein the third coupling mechanism includes a single electron transistor.

51. (previously added) The quantum register of Claim 49, wherein the third coupling mechanism includes a parity key.

52. (previously amended) The structure of claim 1, wherein a qubit is formed by the first bank, the mesoscopic island and the clean Josephson junction, and wherein each quantum state on the qubit is characterized by a clockwise or a counterclockwise supercurrent that circulates in a plane in the vicinity of the clean Josephson junction.

53. (previously amended) The quantum register of claim 8, wherein a plurality of qubits is formed by the plurality of mesoscopic islands, the bank, and the plurality of clean Josephson junctions, and wherein each quantum state on each respective qubit in said plurality of qubits is characterized by a clockwise or a counterclockwise supercurrent that circulates in a plane in the vicinity of the Josephson junction in said respective qubit.

54. (previously amended) The qubit of claim 28, wherein each quantum state on the qubit is characterized by a clockwise or a counterclockwise supercurrent that circulates in a plane in the vicinity of the clean Josephson junction.

55. (previously amended) The quantum register of claim 39, wherein a qubit is formed by each mesoscopic island in the at least one mesoscopic island together with the first bank and a Josephson junction in the at least one Josephson junction, and wherein each quantum state of each said qubit is characterized by a clockwise or a counterclockwise supercurrent that circulates in a plane in the vicinity of the Josephson junction in said qubit.

56. (previously added) The structure of claim 1, wherein a qubit is formed by the first bank, the mesoscopic island and the clean Josephson junction, and wherein the qubit has a quantum state that is twice degenerate in the absence of an external electromagnetic field.

57. (previously added) The quantum register of claim 8, wherein a plurality of qubits is formed by the plurality of mesoscopic islands, the bank, and the plurality of clean Josephson

junctions, and wherein each qubit in said plurality of qubits has a quantum state that is twice degenerate in the absence of an external electromagnetic field.

58. (previously added) The qubit of claim 28, wherein the qubit has a quantum state that is twice degenerate in the absence of an external electromagnetic field.

59. (previously added) The quantum register of claim 39, wherein a qubit is formed by each mesoscopic island in the at least one mesoscopic island together with the first bank and a Josephson junction in the at least one Josephson junction, and wherein each said qubit has a quantum state that is twice degenerate in the absence of an external electromagnetic field.

60. (currently amended) A qubit comprising:

a first bank of a superconducting material having a first crystal orientation;

a mesoscopic island of a superconducting material having a second crystal orientation, wherein at least one of the mesoscopic island ~~islands~~ and the bank comprises a d-wave superconducting material;

a clean Josephson junction between the island and the bank, wherein the Josephson junction is configured so that a supercurrent proximate to the Josephson junction alternates between a first ground state having a first magnetic moment and a second ground state having a second magnetic moment by means of quantum tunneling; and

circuitry to allow selective interruption of quantum tunneling between the first ground state and the second ground state.

61. (previously added) The qubit of claim 60, wherein the circuitry comprises a parity key that connects the island to ground.

62. (previously added) The qubit of claim 60, wherein the circuitry comprises a single electron transistor that connects the island to ground.

63. (previously added) A quantum computer comprising the qubit of claim 60 and a readout device for detecting whether the supercurrent has the first magnetic moment or the second magnetic moment.

64. (currently amended) A quantum register comprising:

a bank of a superconducting material;

a plurality of mesoscopic islands of superconducting material;

a plurality of clean Josephson junctions, wherein each respective Josephson junction:

is between the bank and a corresponding one of the islands; and

is configured so that a supercurrent proximate to ~~each~~ the respective Josephson junction alternates between a first ground state having a first magnetic moment and a second ground state having a second magnetic moment ~~by means of quantum tunneling~~; and

circuitry to allow selective interruption of ~~quantum tunneling~~ the alternating between the first ground state and the second ground state of the supercurrent associated with each Josephson junction, and wherein at least one of the plurality of mesoscopic islands and the bank comprises a d-wave superconducting material.

65. (previously amended) A quantum computer comprising the quantum register of claim 64 and a readout device for detecting whether the supercurrent of each clean Josephson junction has the first magnetic moment or the second magnetic moment.

**Express Mail No.:** **EV 313 841 988 US**

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**
**BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES**

| | | |
|---|---|---|
| In re application of: | ) | Art Unit: 2814 |
| Alexandre M. Zagoskin | ) | Confirmation Number: 1708 |
| Serial No. 09/452,749 | ) | Examiner: Douglas A. Wille |
| Filed: December 1, 1999 | ) | Attorney Docket No: 11090-003-999 |
| For: PERMANENT READOUT SUPERCONDUCTING QUBIT | ) | |

**APPEAL BRIEF**

Mail Stop Appeal Brief - Patents
Honorable Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

Sir:

This is an appeal pursuant to the provisions of 37 C.F.R. § 1.192 from the Examiner's final rejection of claims 1-18 and 28-65 of February 19, 2003. Claims 1, 3-5, 28, 29, 33, 34, 54, 56, 58, and 60-65 were rejected under 35 U.S.C. §103(a) as being unpatentable over Tinkham, *Introduction to Superconductivity*, Second Edition, McGraw-Hill, 1996 (hereinafter "Tinkham"), in view of United States Patent 5,157,466 to Char *et al.* (hereinafter "Char"). Further, claims 2, 30, 31 and 52 were rejected under 35 U.S.C. §103(a) as being unpatentable over Tinkham in view of Char and further in view of Shnirman *et al.*, Physical Review B 57, p. 15400, 1998 (hereinafter "Shnirman"). Further claims 6, 8-10, 35, 39-41, 53, 55, 57, and 59 were rejected under 35 U.S.C. §103(a) as being unpatentable over Tinkham in view of Char and further in view of United States Patent 3,953,749 to Baechtold *et al.* (hereinafter "Baechtold). Claims 7, 11-18, 36, 37, 42, 43, 45, 46, and 48-50 were rejected under 35 U.S.C. § 103(a) as being



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unpatentable over Tinkham in view of Char, Baechtold and further in view of Shnirman. Claims 32, 38, 44, 47, and 51 were also rejected under 35 U.S.C. § 103(a) as being unpatentable over Tinkham in view of Char, Baechtold and further in view of Shnirman.

The Notice of Appeal was filed and received by the United States Patent and Trademark Office on August 15, 2003. This Appeal Brief was originally due on October 15, 2003, for which an extension for a period of one (1) month is hereby requested in the Applicant's concurrently filed Petition for the Extension of Time under 37 C.F.R. § 1.136(a).

A "Brief on Appeal Fee Transmittal" and an amendment under 37 C.F.R. § 1.116 accompanies this brief.

## 1. REAL PARTY IN INTEREST

The real party in interest is D-Wave Systems, Inc. D-Wave Systems, Inc. is a Canadian corporation having headquarters at 320-1985 West Broadway, Vancouver, British Columbia, Canada, V6J 4Y3, by whom the Applicant is employed. An assignment of the invention was recorded on January 24, 2000.

## 2. RELATED APPEALS AND INTERFERENCES

There are no interferences or other appeals related to the present application.

## 3. STATUS OF CLAIMS

On August 15, 2003, Applicant appealed from the final rejection of claims 1-18 and 28-65. Upon entry of a 37 C.F.R § 116 amendment filed on even date herewith, claims 1-8, 11-18, 28, 30-39, and 42-65 remain in the application.

## 4. STATUS OF AMENDMENTS

Applicant has filed an amendment under 37 C.F.R § 116 on even date herewith. All other amendments filed by the Applicant have been duly entered by the Examiner.

## 5. SUMMARY OF THE INVENTION

The present invention is directed to structures used to perform quantum computing. As outlined on page 3, first paragraph, of DiVincenzo in *Scalable Quantum Computers*, Braunstein and Lo, *eds.*, Wiley-VCH, 2001, Berlin, (attached hereto as Exhibit A), a quantum computing device requires qubits. A qubit is a quantum two-level system (DiVincenzo, page 3, first paragraph). The feature that distinguishes a qubit from a bit is that the permitted states of a single qubit fill up a two-dimensional complex vector space $a|0\rangle + b|1\rangle$, where $a$ and $b$ are complex numbers and $|0\rangle$ and $|1\rangle$ are two distinct basis states. A qubit has a nonzero probability of occupying the states $|0\rangle$ and $|1\rangle$ at the same time. See page 2, lines 11-13, as well as page 2, line 20, through page 3, line 6, of the specification. By comparison, a conventional bit can only occupy the states "0" or "1".

For physical intuition of the dynamics of a qubit a particle with mass, termed a "phase particle", is visualized as moving along, under the effect of gravity, in a landscape that defines potential energy barriers. Since the phase particle is governed by quantum mechanics rather than classical mechanics, it is possible for the phase particle to tunnel through the energy barrier separating two ground states ($|0\rangle$ and $|1\rangle$). Tunneling permits the qubit to have a nonzero probability of occupying the two ground states $|0\rangle$ and $|1\rangle$ at the same time. This is in contrast to classical dynamics where a particle cannot tunnel under a barrier and where, to transition from one state to another, it must possess sufficient energy to be able to transition over the potential energy barrier.

The invention is directed to new types of quantum computing devices (*e.g.*, quantum computing structures, quantum registers, qubits) that exploit currents spontaneously arising in a superconductor in the vicinity of a grain boundary Josephson junction. See specification, page 6, lines 18-28. As described on page 3, lines 11-21, as well as Fig. 1A of the specification, these new types of quantum computing devices comprise a superconducting mesoscopic island 120 and a superconducting bank 110 formed on an insulating substrate 140. The mesoscopic island 120 and superconducting bank 110 are separated by a clean Josephson junction 130. At least one of the superconducting bank 110 and superconducting island 120 is a d-wave superconductor, which is a special form of superconductor.

Upon entry of the attached amendment under 37 C.F.R. § 1.116, the structures recited in each of the independent pending claims combines three features to form a quantum computing

device: (i) the use of a d-wave superconductor to form at least one of the superconducting bank 110 and island 120, (ii) a mesoscopic-sized island 120 and (iii) a clean Josephson junction 130 between the superconducting bank 110 and mesoscopic island 120. The purpose of each of these recited features in forming a quantum computing device will be discussed in turn.

5.1 Use of a d-wave superconductor to form at least one of a bank and a mesoscopic island

As explained on page 9, lines 6-17, of the specification, the use of a d-wave superconductor to form at least one of the superconducting bank 110 and mesoscopic island 120 causes persistent supercurrents to arise in the vicinity of clean Josephson junction 130. These persistent supercurrents are illustrated in Fig. 1A of the specification. This is a known phenomenon. For example, the second paragraph in column 1 of Lindström et al., 2003, Physical Review Letters 90, 117002, attached hereto as Exhibit D (hereinafter "Lindström"), notes that "[t]ime-reversal symmetry can ... be spontaneously violated and thus spontaneous currents generated."

5.2 Mesoscopic island

A mesoscopic island 120 is used in the claimed devices so that the phase of the persistent supercurrents discussed in Section 5.1 adopts quantum mechanical behavior rather than classical mechanical behavior. A mesoscopic system is any system that is small enough to be governed by quantum mechanical principles rather than classical mechanical principles. Here, a mesoscopic island 120 is a block of superconducting material that is sufficiently small to be governed by quantum mechanical principles. Generally, in order for island 120 to be mesoscopic, it must have dimensions that are in the low micrometer range or smaller. As noted on page 7, line 30, through page 8, line 2, of the specification, an exemplary mesoscopic island has a width that is 0.2 microns or less, a length of 0.5 micron or less, and a thickness that is 0.2 microns or less. The determination of whether an island 120 is mesoscopic is realized by coherent tunneling of the phase of the persistent supercurrents. Tunneling is a uniquely quantum phenomenon. If island 120 is mesoscopic, then the phase of the persistent supercurrents has a nonzero probability of being in one of two degenerate states. If island 120 is too large to be mesoscopic, then the phase of the persistent supercurrents adopts a constant value, does not have two degenerate ground states, and cannot support quantum computing.

5.3 Clean Josephson junction between a bank and a mesoscopic island

One of the requirements of quantum computing is the establishment of two basis states (*e.g.*, two degenerate states). See specification page 2, lines 11-13. In the novel structures of the present invention, Applicant takes advantage of the properties of a clean Josephson junction in which at least one side of the junction is d-wave superconductor. As noted on page 7, lines 12-14, of the specification, and as illustrated in Fig. 1A, a clean junction 130 separates a bank 110 and island 120. Then, on page 9, lines 6-28, of the specification it is stated that junction 130 causes a non-zero supercurrent in the ground state that is represented by two different states each of which has the same potential energy. In other words, the two different states are degenerate. Page 9 of the specification further states that the two degenerate states correspond to minimal supercurrents circulating through Josephson junction 130 in clockwise and counterclockwise senses. Page 9, lines 15-17, indicate that the two degenerate states associated with the supercurrent on island 120 (*i.e.*, the clockwise and counterclockwise currents respectively) permit quantum computing. The clockwise and counterclockwise supercurrents described on page 9 of the specification serve as the basis states needed for quantum computing. As noted on page 9, lines 27-28, quantum tunneling between these basis states (the two degenerate states) causes the state of island 120 to evolve. This means that the phase of the persistent supercurrents can tunnel through the energy barrier that separates the degenerate state represented by the clockwise persistent supercurrent and the degenerate state represented by the counterclockwise persistent supercurrent through a phenomenon that is known as quantum mechanical tunneling. Furthermore, because the two states are degenerate, this quantum tunneling can occur in both directions (*i.e.*, from $|0\rangle$ to $|1\rangle$ and vice versa) without the application of an external force on the qubit. Due to the quantum mechanical tunneling between the two degenerate states, there is a nonzero probability that states $|0\rangle$ and $|1\rangle$ (where $|0\rangle$ is arbitrarily assigned to either the clockwise or counterclockwise supercurrent and $|1\rangle$ is assigned to the other supercurrent) are occupied at the same time, hence satisfying a central requirement for forming a qubit capable of quantum computation. As noted on page 9 of the specification, the coexistence of the two degenerate ground states results in the coexistence in persistent supercurrents that are traveling in opposite directions (clockwise and counterclockwise as viewed using the framework of Fig. 1A). Because the claimed devices are superconducting, these clockwise and counterclockwise

currents do not interact with each other. Thus, no energy is lost and the persistent supercurrents can coexist for long periods of time. This phenomenon is also described in Lindström et al., 2003, page 117002-1, (Exhibit D) bridging paragraph between columns 1 and 2.

Table 1 summarizes the three novel features of the present invention, how they contribute to the formation of a quantum computing device, and where they are described in the specification.

Table 1. Features that are recited in each pending independent claim.

| FEATURE | CONTRIBUTION | SUPPORT IN SPECIFICATION |
|---|---|---|
| Use of a d-wave superconductor to form at least one of the bank 110 and mesoscopic island 120 across a Josephson junction. | Causes persistent supercurrents to arise in the vicinity of the Josephson junction. | Page 7, lines 6-11 |
| Mesoscopic island 120. | Causes the persistent supercurrents to adopt quantum mechanical behavior, including the ability for the phase of the persistent supercurrents to spontaneously tunnel through a potential energy barrier between degenerate phase states (basis states). | Page 7, line 27, through page 8, line 2 |
| Clean Josephson junction between bank 110 and mesoscopic island 120. | Causes the persistent supercurrents to have two degenerate phase states (basis states). | Page 7, lines 12-16; page 9, line 29, through page 10, line 7 |

## 6. ISSUES

Upon entry of the amendment under 37 C.F.R. § 1.116 filed on even date herewith, the issues presented are:

(1) whether claims 1, 3-5, 28, 33, 34, 54, 56, 58, and 60-65 are patentable under 35 U.S.C. § 103(a) over Tinkham in view of Char;

(2) whether claims 2, 30, 31 and 52 are patentable under 35 U.S.C. § 103(a) over Tinkham in view of Char and further in view of Shnirman;

(3) whether claims 6, 8, 35, 39, 53, 55, 57, and 59 are patentable under 35 U.S.C. § 103(a) over Tinkham in view of Char and further in view of Baechtold;

(4) whether claims 7, 11-18, 36, 37, 42, 43, 45, 46, and 48-50 are patentable under 35 U.S.C. § 103(a) over Tinkham in view of Char, Baechtold and further in view of Shnirman;

(5) whether claims 32, 38, 44, 47, 51 are patentable under 35 U.S.C. § 103(a) over art not specifically identified by the Examiner; and

(6) whether claims 1-8, 11-18, 28, 30-39, and 42-65 are patentable under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claims 1-6, 12, 14, 15, and 18-25 of U.S. Patent No. 6,459,097 in view of Char.

## 7. GROUPING OF CLAIMS

Claims 1-8, 11-18, 28, 30-39, and 42-65 are pending in this case. Many of the pending claims are believed to be separately patentable for the reasons set forth in Section 8 below and do not stand or fall together. In particular, at least the two following groups are believed to be separately patentable:

Group I: claims 1-8, 11-18, 28, 30-39, 42-59, and 64-65; and

Group II: claims 60-63

## 8. ARGUMENTS

### 8.1 Group I: Claims 1, 8, 28, 39, 60, and 64 and each of the claims that depend from these independent claims

In the final office action mailed February 19, 2003, the Examiner rejected claim 1 under 35 U.S.C. § 103(a) as being unpatentable over Tinkham in view of Char. Claim 1 recites (i) a first bank of a superconducting material, (ii) a mesoscopic island of a superconducting material, where at least one of the island and the bank comprises a d-wave superconducting material, and (iii) a clean Josephson junction between the island and the bank. In fact, upon entry of the 37 C.F.R. § 1.116 amendment filed concurrently with this Appeal Brief, each of the independent

claims (claims 1, 8, 28, 39, 60, and 64) recite at least these three elements in a quantum computing device (*e.g.* a quantum computing structure, a quantum register, or a qubit).

The Examiner asserts that page 248, top paragraph, of Tinkham shows a small superconducting island connected to charge reservoirs and further, page 256, last full paragraph, shows a small superconducting island connected to two macroscopic superconducting leads. Next, the Examiner points out that column 2, line 3 et seq. and Fig. 14 of Char show the formation of a grain boundary Josephson junction 314 of high temperature superconductor material where an island 310 is connected to a body 312. The Examiner states that it would have been obvious to use the Char structure for the Tinkham device "since it is known to be functional." Although neither Char nor Tinkham teach or suggest a clean Josephson junction, the Examiner states that it would be obvious to provide the best quality crystal structures since this is standard in semiconductor processing. When rejecting claims under 35 U.S.C. § 103, the PTO bears the burden of establishing a *prima facie* case of obviousness. *In re Bell*, 26 USPQ2d 1529 (Fed. Cir. 1993). To establish a *prima facie* case, the prior art reference, or references when combined, must teach or suggest each and every limitation of the claimed invention. MPEP § 706.02(j). The teaching or suggestion to make the claimed invention and the reasonable expectation of success must both be found in the prior art, not in the Applicant's disclosure. *In re* Vaeck, 20 USPQ2d 1438 (Fed. Cir. 1991). There must be some motivation, suggestion, or teaching of the desirability of making the specific combination that was made by the Applicant. *In re Fine*, 837 F.2d 1071, 1075 (Fed. Cir. 1988).

In the present instance, one relevant inquiry is whether the cited art, either alone or in combination, teaches each and every limitation of the rejected claims. To this end, Applicant submits that the Examiner's rejection of the claims is unfounded because Char and Tinkham, either alone or in combination, do not teach or suggest the clean Josephson junction(s) that are recited in each of the independent claims. Another relevant inquiry is whether the prior art provides one of ordinary skill in the art with a suggestion or motivation to modify or combine the teachings of the references relied upon by the Examiner to arrive at the claimed invention. As discussed in detail below, the cited art fails to satisfy either of these requirements.

### 8.1.1 Char does not teach or suggest a clean Josephson junction

Each of the independent claims recites at least one clean Josephson junction. In the February 19, 2003 Office Action, the Examiner stated that the clean Josephson junction limitation in claim 1 does not render the claim patentable over the combination of Char and Tinkham. The Examiner reasoned that it would have been obvious to provide the best quality crystal structures since this is standard in semiconductor processing. The Applicant will discuss the current-phase relationship of Josephson junctions made from conventional superconducting materials and unconventional superconducting materials in Section 8.1.1.1. Then, the current-phase relationship of clean Josephson junctions will be discussed in Section 8.1.1.2. Then, in subsequent sections, the Applicant will discuss why Char and Tinkham do not teach or suggest clean Josephson junctions and why there is no motivation to modify Char to incorporate clean Josephson junctions into Char devices.

#### 8.1.1.1 Josephson junction current-phase relationships

In general, the current-phase relation of a Josephson junction is described by an odd periodic function commonly represented by the Fourier expansion:

$$I(\varphi) = I_1 \cdot \sin(\varphi) + I_2 \cdot \sin(2\varphi) + \ldots, \qquad (1)$$

where $I_1$ and $I_2$ represent the critical current of the first and second harmonics respectively. In Josephson junctions formed out of conventional superconducting materials, the second harmonic term and higher terms are negligible. See Il'ichev *et al.*, 1999, Physical Review B 60, p. 3096, (hereinafter "Il'ichev 1999"), second column ("The $I_2$ term is also present in weak links based on conventional *s*-wave superconductors but for all known types of weak links $|I_2 / I_1| < 1$. For instance, for a tunnel junction $|I_2 / I_1| << 1$").

The order parameter of a superconducting material determines the properties and characteristics of the superconducting material, and hence the current-phase relationship of weak links formed in the material. Conventional superconducting materials have isotropic order parameters. In contrast, unconventional superconducting materials have anisotropic order parameters. A common unconventional superconducting material is the d-wave superconductor



CA1: 357115.2

$YBa_2Cu_3O_{7-x}$ (YBCO), which is used in both Char and Il'ichev 1999. The term "d-wave" indicates the type of symmetry of the anisotropic order parameter.

Due to the anisotropy of the d-wave order parameter, the current-phase relationship for a Josephson junction in a d-wave superconductor has the potential of having a temperature dependent second harmonic term. The current-phase relationship of the Josephson junctions described in Il'ichev 1999 is:

$$I_P = I_c^I \cdot \sin(\varphi) + I_c^{II} \cdot \sin(2\varphi), \tag{2}$$

where $I_c^I$ and $I_c^{II}$ are the critical currents of the first and second harmonics respectively. Il'ichev 1999 established that the realized non-sinusoidal behavior in the current-phase relationship of this clean Josephson junction is explained by the presence, and in some cases dominance, of the second harmonic term. See, for example, Fig. 4 of Il'ichev 1999, where the second order harmonic $I_2$ dominates over the first order harmonic $I_1$ at lower temperatures.

8.1.1.2 Clean Josephson junctions

The greater the influence of the second harmonic in the current-phase relationship of a Josephson junction, the greater the deviation from conventional $2\pi$ periodic sinusoidal behavior. A clean Josephson junction is defined by a current-phase relationship in which the second harmonic makes a distinct contribution to the characteristics of the junction. (See point 5 of the declaration of Dr. Alexander Tzalenchuk under 37 C.F.R. § 1.132 submitted in response to the February 19, 2003 Office Action on April 18, 2003, attached hereto as Exhibit H). In terms of Eqn. 2, this is the regime where $I_c^{II} > I_c^I / 2$, which causes the equilibrium state to shift from $\varphi=0$, in the sinusoidal case, to about $\pm\pi/2$, creating a double degenerate ground state phase difference across the junction. In other words, the phase differences of about $+\pi/2$ and $-\pi/2$ have equal energy across the unconventional superconductor clean Josephson junction.

The double degenerate ground state associated with a clean Josephson junction is used in the present invention in order to cause persistent supercurrents that spontaneously arise in the claimed devices to have two degenerate ground states. See page 9, lines 6-28, of Applicant's

specification. As discussed in Section 5.1, such persistent supercurrents arise spontaneously in the vicinity of the clean Josephson junction when at least one of bank 110 and island 120 (Applicant's Fig. 1A) is made of a d-wave superconducting material. As discussed in Il'ichev 1999, page 3098, first column, and as depicted in Fig. 4 of Il'ichev 1999 (Exhibit B), the size of the second harmonic is dependent on temperature. It can be suppressed by raising the temperature of the junction. When the second harmonic is suppressed, the junction behaves as a conventional Josephson junction.

8.1.1.3 Char

Char does not teach or suggest clean Josephson junctions. The current-phase relationship of a Josephson junction comprised of a conventional superconducting material has a sinusoidal dependence. See Il'ichev, 1998, Physical Review Letters 81, p. 894, first column, "[t]his sinusoidal dependence has been confirmed experimentally numerous times for standard tunnel junctions between conventional superconductors"). Il'ichev 1998 is attached hereto as Exhibit C. Il'ichev 1998 describes the fabrication of clean Josephson junctions in unconventional superconductors and measurement of their current-phase relationship. Il'ichev 1998 predicted and found significant deviations from the sinusoidal dependence that is typical of conventional Josephson junctions (See Il'ichev 1998, p. 896, first column, "strong deviations from the standard sinusoidal dependence have been predicted for the current-phase relations of various configurations of Josephson junctions employing such unconventional superconductors"). Il'ichev 1999 (Exhibit B) found that the deviations from the sinusoidal dependence were temperature dependent (Il'ichev, page 3098, column 1, "the amplitude of the $\pi$-periodic component of the CPR decreases drastically with increasing temperature").

A review of Fig. 15 of Char is instructive. As illustrated in Fig. 15 of Char, the voltage phase properties of the Char devices illustrate temperature independent conventional sinusoidal behavior, indicating that the second harmonic is suppressed at *all* temperatures in complete contrast to the teachings of Il'ichev 1999 (Exhibit B, p. 3098 column 1, first full paragraph). In other words, Fig. 15 of Char shows that the Char devices "operate properly" (*i.e.*, exhibits $2\pi$ periodic sinusoidal behavior) at temperatures ranging from 4.2K to 77K (see Char, column 15, lines 35-40). This indicates that the Josephson junctions of Char are not in the clean regime. If the Char devices were in the clean regime, then the voltage phase relationship of a Char device

would adopt a sinusoidal waveform at high temperatures (68K) and a non-sinusoidal waveform at low temperatures (4.2K). Fig. 3 of Il'ichev 1999 (p. 3098) shows such a temperature dependence. In Fig. 3 of Il'ichev 1999 (Exhibit B), the non-sinusoidal behavior of a Josephson junction capable of exhibiting second harmonic effects is lost as the temperature of the junction is shifted from 4.2K to 40K. Thus, Char describes Josephson junctions for which the second harmonic is suppressed between 4.2K and 77K. This means that Char does not teach or suggest clean Josephson junctions.

8.1.2 Tinkham does not teach or suggest a clean Josephson junction

Tinkham does not remedy the deficiencies of Char. In particular, Tinkham does not teach or suggest a clean Josephson junction. As noted by the Examiner on page 2 of the February 19, 2003 office action, Tinkham does not detail the materials of the island, leads to the island or Josephson junctions.

8.1.3 There is no motivation in the art to modify Char so that it would have a clean Josephson junction

In the February 19, 2003 Office Action, the Examiner stated that it would have been obvious to provide the best quality crystal structures since this is the standard in semiconductor processing. Applicant respectfully submits that the practice of providing the best quality crystal structures would not have resulted in the modification of Char or Tinkham to include clean Josephson junctions at the time the present application was filed for two reasons. First, the Char devices were constructed using biepitaxial technology. Even the best biepitaxial technology available at the time the present application was filed could not have achieved the unconventional superconductor clean Josephson junctions recited in the pending claims. Second, even if it were possible to modify Char to make the claimed junctions, such junctions would have electrical characteristics that are undesirable for the conventional devices proposed by Char. Because of these undesirable electrical characteristics, their use in the conventional electronic devices described in Char would result in unsatisfactory device performance. This reasoning is outlined in the following subsections.

8.1.3.1 Neither Char nor the best quality crystal structures available for biepitaxial Josephson junction technology at the time of filing of the application were sufficiently advanced to make a clean Josephson junction.

In order to produce a Josephson junction in a d-wave superconducting material such as $YBa_2Cu_3O_7$-x (YBCO), the two sides of the junction must have different crystallographic orientation. There are three general approaches to fabricating such junctions, bicrystal, biepitaxial, and step-edge. See page 1, middle of column 2, of Tafuri *et al.*, cond-mat/0010128.1, Oct. 9, 2000, attached hereto as Exhibit E "YBCO GB junctions are usually classified as bicrystals, biepitaxials, and step-edges, depending on the fabrication procedure." While not intending to be limited to any particular fabrication technique, Applicant discloses a bicrystal fabrication technique on page 8, lines 3-18, of the specification. In Applicant's bicrystal fabrication technique, the substrate itself is a bicrystal substrate, such as a strontium-titanate bicrystal. When a d-wave superconductor such as YBCO is grown or deposited on the bicrystal substrate, it produces two banks having different orientations. On page 8 of the specification, Applicant cites and incorporates by reference Il'ichev *et al.*, 1998 cond-mat/9811017, which is attached hereto as Exhibit F. Page 2, bridging paragraph between columns 1 and 2 of Il'ichev 1998, disclose more details of the bicrystal fabrication technique. Further, the reference demonstrates the successful use of the fabrication technique to make clean Josephson junctions in YBCO. As noted by Tafuri *et al.*, bicrystal techniques typically offer junctions with better performances than biepitaxials (Tafuri, Exhibit E, page 1, second column, "[t]he bicrystal technique typically offers junctions with better performances").

Char uses a biepitaxial technique to form Josephson junctions. In the Char biepitaxial approach, a seed layer is introduced onto a portion of the substrate. See, for example, element 42 in Figs. 3-10 of Char. When YBCO is grown or deposited on a substrate that includes the seed layer, the YBCO overlying the seed layer adopts a different orientation than the portion of the substrate that does not overlay the seed layer. The boundary, therefore, between the YBCO overlying the seed layer and the YBCO overlying the native substrate forms a Josephson junction. See, for example, Fig. 3 of Char, including the Josephson junction (element 30).

Biepitaxial grain boundary Josephson junction technology was not sufficiently advanced at the time of filing of the instant Application to form clean Josephson junctions. This is evidenced by Tafuri (Exhibit E). Tafuri provides new experimental procedures to produce

biepitaxial YBCO Josephson junctions. On page 1 of Tafuri, it is noted that these experimental techniques could *possibly* be used to obtain a Josephson junction that has a double degenerate state [*i.e.*, a clean Josephson junction, "[i]n this paper we discuss how $YBa_2Cu_3O_{7-x}$ (YBCO) structures made by the biepitaxial technique can be successfully employed to produce arbitrary circuit geometries in which both "0" and $\pi$-loops are present, and possibly to obtain a doubly degenerate state"]. Further, it is noted that the biepitaxial techniques of Tafuri represent significant improvements over the biepitaxial techniques of Char (Tafuri, page 1, second column, referencing Char *et al.*, 1991, Applied Physics Letters 59, p. 733, attached hereto as Exhibit G, "we intend to show that significant improvements with respect to the original technique developed by Char et al. are possible for biepitaxial junctions, and that the resulting devices have potential for applications"). The Char *et al.* reference cited by Tafuri is the same biepitaxial technology that is disclosed in United States Patent 5,157,466 to Char. Compare, for example, the text beginning on the second full paragraph on p. 733, column 2 of Char, Applied Physics Letters 59, to column 9, lines 49-64 of United States Patent 5,157, 466. Also, compare Figs. 2, 3, and 4 of Char, Applied Physics Letters 59 to Figs. 13, 14, and 15 of United States Patent 5,157, 466. Clearly, when Tafuri was published, more than ten months after the time of filing Applicant's application, biepitaxial techniques that *might* produce double degenerate (clean) Josephson junctions in YBCO were only first being proposed. Given the difficulties with biepitaxial technology at the time the present application was filed, one of ordinary skill in the art would not have been able to modify Char to produce the devices claimed in the instant application. As such, the combination of Char and Tinkham does not provide a motivation to modify such references in order to make the claimed devices.

#### 8.1.3.2 Unpredictability of the second harmonic in clean Josephson junctions

Even if biepitaxial technology could be used to make a clean Josephson junction, the prior art does not provide a fair motivation to make such junctions. As discussed above, the current-phase relationship of a clean Josephson junction is nonsinusoidal, due to contributions from the second harmonic term, whereas a conventional Josephson junction is sinusoidal, due to the dominance of a first harmonic term and the suppression of a second harmonic term. Further, at least in the case of a YBCO thin film with asymmetric 45 degree [001]-tilt grain boundaries,

the contribution from the second harmonic term in clean Josephson junctions is temperature dependent. Thus, the use of clean Josephson junctions in the devices of Char would introduce an unpredictable temperature dependence on the current-phase dependence in such devices. Since the devices of Char are typically used in applications such as the precise measurement of magnetic fields (Char, column 2, lines 15-17, "[w]eak-link junctions make it possible to create extremely sensitive instruments to measure magnetic field, voltage, and current"), this unpredictable current-phase dependence is undesirable.

The unpredictability in the current-phase relationship of clean Josephson junctions, comes from at least two sources. First, as discussed above and as illustrated in Il'ichev 1999 (Exhibit B, e.g., Figs. 3 and 4), the second harmonic contribution associated with a clean Josephson junction is temperature dependent. Second, as detailed in Il'ichev 1999 and in Lindström, state of the art methods for manufacturing clean Josephson junctions still have not developed to the point where the strength of the second harmonic can be precisely engineered. In Il'ichev 1999, six bicrystal YBCO Josephson junctions were fabricated and studied. Of the six samples, only four produced clean Josephson junctions (Il'ichev 1999, page 3097, column 2, "[w]e have studied six samples, out of which for four samples the $\pi$-periodic component $I(\phi)$ was experimentally observed"). Furthermore the second harmonic contribution of each of the six samples was different (See Il'ichev 1999, column 2, page 3097). Lindström fabricated a number of devices that include Josephson junctions in YBCO using bicrystal techniques. Lindström reported that the critical current varied from sample to sample (Lindström, Exhibit D, page 117002-2, column 2, third full paragraph). Further, Lindström found that the first order and second order harmonics varied by as much as ten times between the two junctions in each of the manufactured devices. (Lindström, page 117002-4, column 1, first paragraph "[t]he ratios of $I_c^I$ and $I_c^{II}$ can vary as much as 10 times between two junctions in the same SQUID"). Thus, even the state of the art methods for manufacturing clean Josephson junctions such as Il'ichev 1999 and Lindström have failed to make clean Josephson junctions with consistent second order harmonics.

The results of Il'ichev 1999 and Lindström show that each clean Josephson junction would have to be characterized to determine the magnitude of the first and second harmonics. Such a step is not presently needed in Char and there is simply no motivation to alter Char to introduce such a step since Char does not teach or suggest the use of devices that make use of the

second order harmonics of clean Josephson junctions. In contrast, characterization of each clean Josephson junction for use in the quantum devices claimed by Applicant provides no drawback.

### 8.1.4 The prior art provides no motivation to combine Tinkham and Char

If it is not shown that the prior art gives a reason or motivation to make the claimed invention, then there is no *prima facie* case and the Applicant should prevail. *In re Grabiak*, 769 F.2d 729 (Fed Cir 1985). It is improper to use hindsight reconstruction based upon the disclosure of the Applicant's own specification. These type of hindsight rejections are specifically prohibited. See *In re Vaeck*, 947 F.2d 488, 493, 20 U.S.P.Q.2d 1438, 1442 (Fed. Cir. 1991); and *In re Fine*, 837 F.2d 1071, 1075, 5 U.S.P.Q.2d 1596 (Fed. Cir. 1988).

Even if Char were combined with Tinkham, the present invention would not be obvious since neither of them teaches the specific claimed structures as explained above. In addition, there is nothing in the references to motivate one of ordinary skill in the art to modify the structures disclosed in the cited references to arrive at the claimed invention. The Applicant's own disclosure cannot be used to fill the gap between the cited references and the claimed invention.

### 8.1.5 Conclusion

For the above-identified reasons, claims 1, 8, 28, 39, 60, and 64 are patentable over any combination of Tinkham and Char. Furthermore, all other pending claims depend from one of these claims and are therefore patentable over the combination of Tinkham and Char for at least the same reasons. Certain claims are rejected as being unpatentable over Tinkham, in view of Char and further in view of Baechtold. However, Baechtold merely teaches a binary circuit consisting of a series/parallel arrangement of Josephson junctions. As such, Baechtold does not remedy the above-identified deficiencies in the combination of Tinkham and Char. Certain of the claims are rejected as being unpatentable over Tinkham, in view of Char, in view of Shnirman. However, Shnirman merely teaches a single-electron transistor capacitively coupled to a Josephson junction qubit. As such, Shnirman does not remedy the above-identified deficiencies in the combination of Tinkham and Char. Certain of the claims are rejected as being unpatentable over Tinkham, in view of Char, Baechtold, and further in view of Shnirman. None of these references, either alone or in combination, remedy the above-identified deficiencies. For

these reasons, all the claims are patentable over any combination of Tinkham, Char, Baechtold, and Shnirman. Additional reasons for patentability of some of the pending claims are provided in the following subsection.

8.2 Group II: Claims 60-63

Claims 60-63 are directed to a qubit with circuitry to allow selective interruption of quantum tunneling between a first ground state and a second ground state. In the February 19, 2003, Office Action, the Examiner stated that claims 60-63 are unpatentable over Tinkham in view of Char because Char shows a superconducting quantum interference device (SQUID) and the Examiner argued that tunneling occurs in such devices. While tunneling may in fact occur in such devices, it is not quantum tunneling as claimed in claims 60-63. Quantum tunneling can only arise in a mesoscopic system. Char does not teach or suggest a SQUID that is mesoscopic. Tinkham teaches a mesoscopic island but does not teach or suggest a SQUID. Furthermore, there is no suggestion in either reference nor any motivation in the art to combine the two references to make a mesoscopic SQUID.

8.3 The rejection of the pending claims under the judicially created doctrine of obviousness-type double patenting has been overcome.

Claims 1-18 and 28-65 were provisionally rejected under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claims 1-6, 12, 14, 15, and 18-25 of U.S. Patent No. 6,459,097 in view of Char. With respect to claims 9, 10, 29, 40, and 41, the rejection is moot because these claims have been canceled. A Terminal Disclaimer in compliance with 37 CFR 1.321 was submitted on April 18, 2003 along with the April 18, 2003 response to the February 19, 2003 Final Office Action. Accordingly, reversal of the double patenting rejection is respectfully requested.

## 9. CONCLUSION

For all of the foregoing reasons, reversal of the rejections of claims 1-8, 11-18, 28, 30-39, and 42-65 is respectfully requested.

Respectfully submitted,
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## APPENDIX A

## APPEALED CLAIMS (UPON ENTRY OF THE ACCOMPANYING AMENDMENT UNDER 37 C.F.R. § 1.116)

1. (previously amended) A quantum computing structure comprising:

a first bank of a superconducting material having a first crystal orientation;

a mesoscopic island of a superconducting material having a second crystal orientation, wherein at least one of the island and the bank comprises a d-wave superconducting material; and

a clean Josephson junction between the island and the bank.

2. (original) The structure of claim 1, further comprising a single electron transistor connected between the island and ground.

3. (previously amended) The structure of claim 1, wherein the clean Josephson junction comprises a grain boundary between the bank and the island.

4. (original) The structure of claim 1, wherein the island comprises a d-wave superconducting material.

5. (original) The structure of claim 4, wherein the bank comprises a d-wave superconducting material.

6. (original) The structure of claim 1, further comprising:

a second bank of superconducting material having a third crystal orientation; and

a Josephson junction between the first and second banks.

7. (original) The structure of claim 6, further comprising a single electron transistor coupled between the second bank and the island.

8. (currently amended) A quantum register comprising:

a bank of a superconducting material;

a plurality of mesoscopic islands of superconducting material; and

a plurality of clean Josephson junctions, each clean Josephson junction being between the bank and a corresponding one of the islands<u>, wherein at least one of the plurality of mesoscopic islands and the bank comprises a d-wave superconducting material</u>.

9-10. (cancelled)

11. (original) The quantum register of claim 8, further comprising a plurality of single electron transistors, each electron transistor being between ground and a corresponding one of the islands.

12. (original) The quantum register of claim 8, further comprising a first plurality of single electron transistors, each single electron transistor in the first plurality being between islands in a corresponding pair of the islands.

13. (previously amended) The quantum register of claim 12, further comprising a second plurality of single electron transistors, each single electron transistor in the second plurality being between ground and a corresponding one of the plurality of mesoscopic islands.

14. (original) The quantum register of claim 8, further comprising:

a second bank of superconducting material; and

a Josephson junction between the first and second banks.

15. (original) The quantum register of claim 14, further comprising a first plurality of single electron transistors, each single electron transistor being coupled between the second bank and a corresponding one of the islands.

16. (original) The quantum register of claim 15, further comprising a second plurality of single electron transistors, each single electron transistor in the second plurality being between ground and a corresponding one of the islands.

17. (original) The quantum register of claim 15, further comprising a second plurality of a single electron transistors, each single electron transistor in the second plurality being between islands in a corresponding pair of the islands.

18. (previously amended) The quantum register of claim 17, further comprising a third plurality of single electron transistors, each single electron transistor in the third plurality being between ground and a corresponding one of the plurality of mesoscopic islands.

28. (currently amended) A qubit, comprising:

a first bank of a superconducting material having a first crystal orientation;

a mesoscopic island having a second crystal orientation formed adjacent to the first bank; and

a clean Josephson junction formed between the first bank and the mesoscopic island, wherein the first crystal orientation and the second crystal orientation are different <u>wherein at least one of the mesoscopic island and the first bank comprises a d-wave superconducting material</u>.

29. (cancelled)

30. (previously added) The qubit of Claim 28, further including a grounding mechanism coupled between the mesoscopic island and a ground.

31. (previously added) The qubit of Claim 30, wherein the grounding mechanism is a single electron transistor.

32. (previously added) The qubit of Claim 30, wherein the grounding mechanism is a parity key.

33. (previously added) The qubit of Claim 28, wherein the clean Josephson junction includes a grain boundary between the island and the first bank.

34. (previously added) The qubit of Claim 28, wherein the clean Josephson junction includes a normal metal.

35. (previously added) The qubit of Claim 28, further comprising:

a second bank of superconducting material having a third crystal orientation; and

a Josephson junction formed between the first bank and the second bank.

36. (previously added) The qubit of Claim 35, further comprising:

a coupling mechanism coupled between the mesoscopic island and the second bank.

37. (previously added) The qubit of Claim 36, wherein the coupling mechanism includes a single electron transistor.

38. (previously added) The qubit of Claim 36, wherein the coupling mechanism includes a parity key.

39. (currently amended) A quantum register, comprising:

a first bank of superconducting material;

at least one mesoscopic island of a superconducting material; and

at least one clean Josephson junction, each clean Josephson junction in said at least one clean Josephson junction formed between a mesoscopic island in the at least one mesoscopic island and the first bank, wherein at least one of the at least one mesoscopic island and the first bank comprises a d-wave superconducting material.

40-41. (cancelled)

42. (previously added) The quantum register of Claim 39, further including at least one first coupling mechanism, each of the at least one first coupling mechanisms coupling a corresponding one of the at least one mesoscopic islands to ground.

43. (currently amended) The quantum register of Claim 42, wherein ~~at~~ said at least one ~~of the~~ first coupling mechanism ~~mechanisms~~ includes a single electron transistor.

44. (currently amended) The quantum register of Claim 42, wherein ~~at~~ said at least one ~~of the~~ first coupling mechanism ~~mechanisms~~ includes a parity key.

45. (currently amended) The quantum register of Claim 39, wherein said at least one mesoscopic island includes a ~~at least one~~ pair of mesoscopic islands that are coupled to each other by a second coupling mechanism.

46. (previously added) The quantum register of Claim 45, wherein the second coupling mechanism includes a single electron transistor.

47. (previously added) The quantum register of Claim 45, wherein the second coupling mechanism includes a parity key.

48. (previously added) The quantum register of Claim 39, further including:

a second bank of superconducting material; and

a Josephson junction formed between the second bank and the first bank.

49. (currently amended) The quantum register of Claim 48, further including ~~at least one~~ a third coupling mechanism coupled between ~~one of the~~ a mesoscopic ~~islands~~ island in said at least one mesoscopic island and the second bank.

50. (previously added) The quantum register of Claim 49, wherein the third coupling mechanism includes a single electron transistor.

51. (previously added) The quantum register of Claim 49, wherein the third coupling mechanism includes a parity key.

52. (previously amended) The structure of claim 1, wherein a qubit is formed by the first bank, the mesoscopic island and the clean Josephson junction, and wherein each quantum state on the qubit is characterized by a clockwise or a counterclockwise supercurrent that circulates in a plane in the vicinity of the clean Josephson junction.

53. (previously amended) The quantum register of claim 8, wherein a plurality of qubits is formed by the plurality of mesoscopic islands, the bank, and the plurality of clean Josephson junctions, and wherein each quantum state on each respective qubit in said plurality of qubits is characterized by a clockwise or a counterclockwise supercurrent that circulates in a plane in the vicinity of the Josephson junction in said respective qubit.

54. (previously amended) The qubit of claim 28, wherein each quantum state on the qubit is characterized by a clockwise or a counterclockwise supercurrent that circulates in a plane in the vicinity of the clean Josephson junction.

55. (previously amended) The quantum register of claim 39, wherein a qubit is formed by each mesoscopic island in the at least one mesoscopic island together with the first bank and a Josephson junction in the at least one Josephson junction, and wherein each quantum state of each said qubit is characterized by a clockwise or a counterclockwise supercurrent that circulates in a plane in the vicinity of the Josephson junction in said qubit.

56. (previously added) The structure of claim 1, wherein a qubit is formed by the first bank, the mesoscopic island and the clean Josephson junction, and wherein the qubit has a quantum state that is twice degenerate in the absence of an external electromagnetic field.

57. (previously added) The quantum register of claim 8, wherein a plurality of qubits is formed by the plurality of mesoscopic islands, the bank, and the plurality of clean Josephson

junctions, and wherein each qubit in said plurality of qubits has a quantum state that is twice degenerate in the absence of an external electromagnetic field.

58. (previously added) The qubit of claim 28, wherein the qubit has a quantum state that is twice degenerate in the absence of an external electromagnetic field.

59. (previously added) The quantum register of claim 39, wherein a qubit is formed by each mesoscopic island in the at least one mesoscopic island together with the first bank and a Josephson junction in the at least one Josephson junction, and wherein each said qubit has a quantum state that is twice degenerate in the absence of an external electromagnetic field.

60. (currently amended) A qubit comprising:

a first bank of a superconducting material having a first crystal orientation;

a mesoscopic island of a superconducting material having a second crystal orientation, wherein at least one of the mesoscopic island ~~islands~~ and the bank comprises a d-wave superconducting material;

a clean Josephson junction between the island and the bank, wherein the Josephson junction is configured so that a supercurrent proximate to the Josephson junction alternates between a first ground state having a first magnetic moment and a second ground state having a second magnetic moment by means of quantum tunneling; and

circuitry to allow selective interruption of quantum tunneling between the first ground state and the second ground state.

61. (previously added) The qubit of claim 60, wherein the circuitry comprises a parity key that connects the island to ground.

62. (previously added) The qubit of claim 60, wherein the circuitry comprises a single electron transistor that connects the island to ground.

63. (previously added) A quantum computer comprising the qubit of claim 60 and a readout device for detecting whether the supercurrent has the first magnetic moment or the second magnetic moment.

64. (currently amended) A quantum register comprising:

a bank of a superconducting material;

a plurality of mesoscopic islands of superconducting material;

a plurality of clean Josephson junctions, wherein each respective Josephson junction:

is between the bank and a corresponding one of the islands; and

is configured so that a supercurrent proximate to ~~each~~ the respective Josephson junction alternates between a first ground state having a first magnetic moment and a second ground state having a second magnetic moment ~~by means of quantum tunneling~~; and

circuitry to allow selective interruption of ~~quantum tunneling~~ the alternating between the first ground state and the second ground state of the supercurrent associated with each Josephson junction, and wherein at least one of the plurality of mesoscopic islands and the bank comprises a d-wave superconducting material.

65. (previously amended) A quantum computer comprising the quantum register of claim 64 and a readout device for detecting whether the supercurrent of each clean Josephson junction has the first magnetic moment or the second magnetic moment.